U. S. DEPARTMENT OF AGRICULTURE.

FARMERS' BULLETIN No. 239.

THE CORROSION OF FENCE WIRE.

BY

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF PUBLIC ROADS,
Washington, D. C., November 13, 1905.

I have the honor to transmit herewith for publication as a Farmers'
Bulletin of this Department a manuscript setting forth the results
of an investigation of the corrosion of iron and steel wire used for
fencing. So many complaints have reached the Department from
time to time that it has seemed urgently necessary to inform the
farmers of the country regarding the facts of the case and to bring
about, so far as is possible, an improvement in present conditions.

Respectfully,

LOGAN WALLER PAGE, *Director.*

Hon. JAMES WILSON,
Secretary of Agriculture.

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THE CORROSION OF FENCE WIRE.

INTRODUCTION.

The investigation of which this bulletin is in part a record has been carried on with a twofold purpose in view. The first object is to furnish information to the farmer which will enable him to exercise an intelligent judgment as to the difficulties involved in the manufacture of wire fencing which shall be low in price and at the same time resistant to rust and corrosion. The second object has been to determine, with the cooperation of progressive manufacturers and metallurgists, the causes which underlie the much too rapid corrosion of modern steel wire, and, if possible, to suggest improvements in methods of manufacture by means of which the difficulties may be at least partially, if not wholly, overcome. There is reason to hope that at least something has been accomplished and that the future will show a substantial improvement in the lasting quality of the galvanized wire turned out by the manufacturers.

The earlier correspondence that was carried on in the effort to get at the facts showed that a great many farmers believe that the manufacturers have neither the intention nor the desire to make the best possible wire. On the other hand, some manufacturers held that, if it were possible to make a higher grade of wire at even a slightly higher cost, it would be useless to attempt it, as the farmer desires cheapness above every other consideration. It is safe to say that neither of these extreme views has been substantiated by the evidence gathered during the progress of this investigation. The majority of farmers in this country know that a fence that will last in good condition for twenty years is cheaper than one that costs one-half as much money and is useless in five years. It is equally true that American manufacturers have for the most part shown themselves not only willing but anxious to contribute in every possible way to the success of the investigation, and have given evidence of their desire to make the best product consistent with their knowledge and the trade conditions that have to be met.

It is frequently asserted that wire for fencing is manufactured from the refuse of the furnaces and the junk piles, and that the metal used

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in forming the galvanized coating is largely adulterated with metals cheaper than zinc. The first contention shows ignorance of the fact that refuse metal of this kind could never be drawn to the form of wire, and that any manufacturer who followed such methods would speedily find his finished product upon his own junk pile; and as to the second contention it may be said that, if it is true, no indication of the fact has been discovered during the course of the investigation.

It is therefore presumed in this discussion that the farmer desires to purchase fencing that will be good and at the same time as cheap as is consistent with the greatest efficiency and economy, and that the manufacturer is willing to supply this legitimate demand so far as he can.

The real cause of the trouble is a metallurgical problem and requires careful and impartial consideration. This bulletin is an effort to give all the evidence obtainable up to the present time, and also a short, simple description of the modern methods of iron and steel manufacture and of the processes involved in making the wire. It also contains evidence pointing to what may turn out to be the real cause of the trouble and suggestions for possible future improvement. Highly technical discussion and purely scientific suggestions have been put into an appendix for the consideration of those who are likely to be interested in them.

For some time past numerous complaints from different sources have reached the Department concerning the inferior lasting quality of the steel-wire fencing which is to be found in the market at the present time. Among the various statements of fact and explanations which have been advanced, whether supported by sufficient evidence or not, the following may be cited to show the necessity for a thorough investigation of the subject in all its bearings:

(1) That, while the older wire, purchased twenty or more years ago, is frequently found still in good condition, modern wire goes to pieces in from two to five years.

(2) That iron wire resists oxidation better, and therefore is more durable than steel wire.

(3) That the entire difficulty lies in the use of Bessemer steel, and that puddled iron is far better suited to the purpose.

(4) That heavier weight wire was used in the older product, and hence its lasting quality.

(5) That the trouble is wholly caused by the inferior weight and quality of the modern galvanized coating, and that the character of the metal itself has nothing to do with it.

(6) That in order to cheapen the product lead and other adulterants are added to the zinc spelter bath used in making the galvanized coating, and that the methods in use at present are in general inferior to the older methods.

(7) That the manufacturers do not desire to make a resistant wire, but prefer a product that will require frequent renewal.

(8) That the majority of farmers and other consumers prefer cheapness to any other consideration, and that if a better product can be manufactured for a higher price there will be little or no market for it.

(9) That the whole agitation is ridiculous and unnecessary, as better wire is now being manufactured than ever before, and that the whole trouble lies in the greater amount of coal that is at present consumed, leading to an increase of corroding gases in the atmosphere.

(10) That the manufacturers are aware that all is not right and are anxious to do all in their power to improve the durability of their product.

While some of these claims may be considered extreme, they also contain much that is true and worthy of careful investigation. At all events, a very large amount of evidence can easily be obtained to show the truth of the original contention that the older iron wire is much more durable than modern steel wire.

In order to collect all the information possible, a circular letter containing a number of questions bearing upon the subject was sent to the leading manufacturers in the country. Space will not allow all the answers obtained to be published, but the questions, with the answers received from two of the largest manufacturers in the country (here designated as A and B), are inserted:

(1) Is the wire manufactured by you for fencing classed as iron, mild steel, or steel?

A. Steel and mild (soft) steel.

B. Our fencing wire is classed as steel.

(2) In case more than one kind or brand of wire is manufactured by you, do these all fall into one class as defined in question 1?

A. No. Steel produces a relatively stiff wire of high tensile strength; mild or soft steel produces softer wire of less tensile strength.

B. All fence wire is classed as steel. Telephone wire in different grades is classed as both iron and steel.

(3) Do you classify wire as iron, mild steel, or steel, according to the original process of manufacture, or according to the amount and condition of the carbon content?

A. According to the carbon content.

B. We have three classifications, and these are based mainly according to the amount and condition of the carbon content.

(4) What is the original process of manufacture of the metal from which your wire is drawn, viz, Bessemer, open-hearth, etc.?

A. Bessemer and open-hearth.

B. Steel, Bessemer or open-hearth Bessemer equivalent; B. B. iron, low carbon open-hearth basic steel; E. B. B. iron, genuine Swedish charcoal iron.

(5) What system of annealing do you follow?

A. Either through molten lead at a red heat or through fire brick tubes at a red heat.

B. Fence wire is annealed by the lead process; telephone wire is annealed by the tubular furnace process.

(6) In case of galvanized wire or wire otherwise coated with a metallic protective coating, what method of pickling is followed? If an acid is used, what

acid, and of what strength? Is the wire thoroughly washed after leaving the pickling bath?

 A. Muriatic acid is used, of a strength equal to 10° Baumé. The wire is thoroughly washed after leaving the pickling bath.

 B. Muriatic acid (18°) is used for pickling, which is not washed off; the wire passes directly into the zinc bath. The muriatic acid solution is intended to act as a soldering solution.

(7) In the case of galvanized wire, what metal or mixture of metals is used to produce the protective coating?

 A. Pure commercial zinc.

 B. For fence wire, prime western spelter is used; for telephone wire, high-grade spelter made from pure zinc oxide.

(8) What weight of the protective coating for a unit weight of wire do you aim to cover with?

 A. From $2\frac{1}{2}$ to $3\frac{1}{2}$ per cent.

 B. Fence wire, 80 to 90 pounds of zinc per 1 ton of wire; telephone wire, 140 to 150 pounds of zinc per 1 ton of wire.

(9) At what temperature is the bath maintained in which the galvanizing process is carried on?

 A. 800° to 850° F.

 B. The temperature of the zinc bath is maintained at a sufficiently high point to keep the metal in a uniform flowing condition.

(10) Is it your opinion that a more durable and resistant wire could be manufactured if the trade conditions permitted a reasonably higher price being asked for it?

 A. We manufacture the best wire we know how to produce.

 B. Yes.

(11) Would you be willing to write us a letter containing your experience in regard to the accompanying five statements?

I. That modern steel wire corrodes more rapidly than the older wire that was found in the market, say, from ten to twenty years ago.

II. That this older wire retains its galvanized cover better than the steel wire now produced.

III. That the galvanizing processes are not in every case as efficient as they could be made.

IV. That the degree of tension under which the wire is hung may have an effect upon the life of the protective coating.

V. That the action of certain gases in the atmosphere which result from the consumption of coal exerts an influence upon the durability of fence wire.

 A. We submit the following answers:

 I. Modern steel wire is better and more uniform, and can be made more uniformly soft to-day than it could be made ten or twenty years ago. We are unable to discover that steel wire corrodes more rapidly. We are convinced, however, that iron wire, when galvanized with zinc, resists corrosion more perfectly than steel wire.

 II. The fence wire we are making to-day is superior to that made ten and twenty years ago. The spelter is more uniformly applied and the coating heavier, and, as we are manufacturers of our own spelter, its quality is maintained more uniform.

 III. Our galvanizing processes have been improved from year to year, and the uniform quality of the wire produced is very good.

 IV. In our opinion the tension under which the wire is hung has no effect whatever on the life of the protective coating.

 V. Around chemical works, wire mills, etc., where acid fumes are in the air and are absorbed or where other factories, as well as railroads, are located which contaminate the atmosphere with large quantities of coal smoke, conditions are very destructive to zinc covering. This is more especially true in districts where fuel containing large percentages of

sulphur is used. This pollution of the atmosphere to-day is much more severe on zinc-coated wire than twenty years ago.

B. We will be very glad indeed to assist the Department of Agriculture in any way possible, and if we can serve you, command us.

(12) Are you willing to supply the Division of Tests with test samples of your various brands of wire?

A and *B.* Yes.

It will be seen from the above that while one of these correspondents believes that his company is making the best wire possible, the other admits that better wire could be used for fencing if the price permitted. There is no question but that the higher-priced wire that is manufactured for telegraphic purposes is more durable than that used for fencing, and the reasons for this will be developed in the course of this paper.

MANUFACTURE OF IRON AND STEEL.

Before the farmer or any other user of steel wire can intelligently consider the problem of the corrosion and deterioration of iron and steel it is necessary that he should be to some extent familiar with the methods of manufacture, the system of classification, and some of the effects of the ordinary impurities.

Iron as it is manufactured from its ores is never pure, nor would perfectly pure iron be suitable for the various purposes for which the metal is used. Iron is found in nature combined with oxygen in the form of an oxide, in which it occurs in great reddish-brown or bluish rock-like deposits known as hematite and limonite. There are several oxides of iron which differ from each other in the relative amount of oxygen which is combined with the iron. The ordinary red oxide which forms when iron rusts is essentially the same oxide that occurs in nature as hematite ore.

HOW CAST IRON IS PRODUCED.

In rusting, oxygen is added to the iron, and in smelting the ore, oxygen has to be taken away from the iron. To do this, ore is mixed with coke and limestone and heated in large furnaces so arranged that a blast of hot air can be forced in through suitable holes near the bottom. Air consists mainly of a mixture of oxygen and nitrogen gases and at the high temperature of the blast furnace a great many things happen. Coke is almost pure carbon and when it burns in the furnace it not only combines with all of the oxygen of the air but also takes away all of the oxygen which was combined with the iron in the ore, passing out of the stack in the form of gases. The metallic iron is thus set free in a liquid or molten condition, in which it falls to the bottom, or hearth, of the furnace.

Now, however, we come to an important point. Carbon is very

soluble in molten iron, and as more than enough carbon to combine with the oxygen is always present the molten metal is really a solution of carbon in iron. This simply means that the carbon goes into the iron just as sugar or salt will pass into water. At definite times the molten metal is allowed to run out of the tap hole of the furnace into a series of sand molds which is known as the pig bed. There the iron cools more or less rapidly, but as it cools another very important thing happens—part of the dissolved carbon crystallizes out into hard crystals of solid carbon as the mass takes on the solid condition, while the rest of the carbon remains in the iron and does not crystallize out. The carbon which does not crystallize out is now believed to be in part combined with the iron and in part held in a state known scientifically as " solid solution," but by the iron metallurgist it is spoken of as " combined carbon." The crystalline carbon is far more like black diamond than it is like the soft, greasy variety of carbon known as graphite, from which lead pencils are made, and yet the iron metallurgist has come to speak of this free carbon in his metal as " graphitic."

Besides carbon, the molten iron either dissolves or combines with several other substances that are of the very greatest importance in the metallurgy of iron. These are sulphur, phosphorus, silicon, and manganese. All these so-called elements are introduced into the furnace, not necessarily on purpose, but as impurities in the ore, coke, and limestone; and, while, if not properly controlled, they become very harmful, some of them, like carbon and silicon, are absolutely necessary to the proper working of the iron.

Pig iron is the crude form of iron, the raw material for the manufacture of all the finished grades of iron and steel. When simply melted up in a reheating or cupola furnace and cast into shapes, such as car wheels, a good iron may have the following analysis:

	Per cent.		Per cent.
Total carbon	3.50	Manganese	0.40
Graphitic carbon	2.90	Phosphorus	.50
Combined carbon	.60	Sulphur	.08
Silicon	.70		

As is well known, cast iron can not be forged into shapes or drawn into wire, on account of its crystalline granular structure. In order to render iron suitable for working in this way, it must be changed by some process into what is known as wrought iron or into steel.

We are now in a position to consider briefly what is meant by expression (so frequently used in relation to wire problems) such as Bessemer steel, basic open-hearth steel, puddled iron, and mild and high-carbon steel. In the simplest language, the whole process of

converting cast iron into a workable metal, by whatever name it may be known, consists in remelting the metal in the presence of a great excess of hot air, so that nearly all, though usually not quite all, of the carbon is burned away, while in some of the processes certain of the other impurities already mentioned are more or less completely removed.

THE BESSEMER PROCESS.

The Bessemer process is the great modern method for converting iron into steel, and on account of its simplicity of operation and the large amounts of metal that can be worked at each charge, it has not only been of the greatest benefit to the iron industry, but, by making steel cheap, has produced a wonderful effect upon the progress of civilization. The only question in the minds of thoughtful metallurgists to-day is whether it has not been overdone and whether, indeed, it is best suited for the manufacture of metal that is destined to be drawn into wire or rolled into thin sheets. An expert discussion of this question will be found in the Appendix (pages 25–30).

Described briefly, the Bessemer process consists of pouring molten cast iron into a large pear-shaped vessel called a " converter," furnished with a number of small holes in the bottom through which a blast of air is forced under high pressure. By this means the carbon is nearly all burned out, together with the silicon. The iron, too, is slightly burned, and after the blow is over a certain amount of manganese, in the form of lumps of an alloy or combination of manganese and iron known as ferro-manganese, is thrown into the converter before the metal is poured into the molds to cool. These cooled blocks of steel are known as " ingots." This addition of manganese is a very important point in the metallurgy of steel, and, as we shall have occasion in this paper to return to it frequently, it is necessary that the various reasons for the operation should be understood.

(1) If the molten metal were to be immediately poured after the blow, it would be found on cooling to be full of cavities known as " blow holes," caused by the retention in the metal of gases from the air blast, and would be quite unfit for any purpose whatever. For reasons which it is not necessary to explain here, the action of even the small amount of manganese that is added is almost magical in its effect. The burned iron is again reduced or deoxidized, the mass of metal becomes more perfectly fluid, the gases escape, and the metal pours smoothly and evenly. In other words, the manganese acts as a so-called " flux."

(2) Just as small quantities of carbon dissolved in iron change and modify its properties, so small quantities of other substances produce · their own effects. Manganese is supposed to decrease the danger of

breaking up as the metal passes hot through the rolls in the "rod mills."

It is now apparent that manganese plays an important rôle in the Bessemer process, and, in fact, Bessemer steel will generally be found to contain anywhere from 0.4 to 1 per cent of manganese.

BASIC OPEN-HEARTH PROCESS.

Phosphorus and sulphur both have a deleterious effect upon steel, reducing the ductility and making the metal brittle. In a process like the one just described, it is necessary to specify that the pig iron shall contain below a certain percentage of phosphorus. This would, of course, exclude much of the pig iron that is manufactured, as phosphorus in some of its combinations is almost always found in iron ore. By making the lining of the furnace out of a material that will combine with elements like phosphorus, which easily combines with oxygen to form phosphoric acid, much of this impurity may be made to combine with the furnace lining and to remove itself from the metal by entering the slag floating on top of the molten mass. Without going further into the chemistry of the subject, this is all that is meant by basic open-hearth steel, namely, that the pig iron is melted in large basin-shaped furnaces in which the carbon is burned out by the play of hot air over the surface of the molten mass, while at the same time the acid-forming impurities, such as phosphorus and silicon, are absorbed by the basic lining of the furnace, which is usually made of a rock material found in nature, consisting of carbonate of lime and magnesia, and known as "dolomite." Lime or limestone is also added to hasten this action and save the lining. With the exception that the hot air is not blown through the molten metal, the open-hearth process is much like the Bessemer. At the end of the run ferro-manganese is thrown into the liquid bath of metal to flux it. This is done sometimes in the furnace and sometimes in a ladle into which the metal is tapped. It is then run off into the ingot molds to cool in the usual way. It will be noted that the open-hearth process depends essentially, as does the Bessemer, upon refluxing with manganese.

PUDDLED IRON.

It only remains now to outline briefly the older puddling method by which wrought iron was made, which yielded most of the extremely durable wire that was found in the market many years ago. This process consists essentially of heating the iron in flat-shaped furnaces to a more or less fluid or pasty condition and then working it over and over in the presence of air by means of special tools known as "rabbles," in the hands of skilled workmen. By this means the

impurities are oxidized and burnt off, and the slag or cinder which always forms is worked into the metal, so that when it comes to be rolled not only are the impurities very evenly distributed throughout the mass, but it possesses the structure of a bundle of fibers, each one of which is coated with a film of cinder, which protects it in very large measure from subsequent rusting. This cinder is composed of oxide of iron combined with silica, which comes from the fire-clay lining of the furnace, for in this process basic linings are not used.

In the minds of most metallurgists some sort of return to this older method would be the best solution of the problem of the manufacture of wire which would resist oxidation, but the trouble lies in the impossibility of competing with the price of metal manufactured by the more economical modern processes. It must be apparent to everyone that the high price of labor would not permit hand-worked metal to compete on a large scale with that produced by modern methods. It has, however, been proposed to use a form of mechanical puddling which would be capable of treating at one time charges of metal as large as those used in the Bessemer process. It is not impossible that eventually this will furnish a solution of the difficulty.

It may be added that Swedish charcoal iron is a modified form of wrought iron, in which the impurities run very low. At the present time no charcoal iron is manufactured in this country for fence wire.

MILD AND HIGH-CARBON STEELS.

As has already been pointed out, steel is to be considered as an alloy or solution in varying proportions of carbon in iron. It may now be said that within certain limits the higher the carbon content the harder the steel. Mild steel is that in which the carbon rarely runs above 0.1 to 0.2 per cent, while in hard steel the carbon may run as high as 1 per cent or even higher.

The following analyses may be taken as fairly typical of the various kinds of metal we have been discussing, although these figures may of course vary widely with the different degrees of hardness that the manufacturer desires to obtain:

Constituents.	Bessemer steel.	Basic [a] open-hearth steel.	Swedish puddled iron.
	Per cent.	Per cent.	Per cent.
Carbon	0.10	0.70	0.04
Manganese	.50	.50	.06
Sulphur	.08	.06	.01
Phosphorus	.102	.05	.01

[a] Open-hearth metal may run much lower in carbon and much higher in manganese than these figures indicate. Some samples which have been received ran as high as 1.5 per cent manganese.

The presence of these various impurities complicates the difficulty in tracing the trouble to any one element. In some grades of wire it is said to be a positive advantage to have high phosphorus and silicon, but in fence-wire stock these elements are present in comparatively small quantity, while the carbon and manganese run high. It will be noticed that the amount of impurities in the Swedish iron is extremely small.

MANUFACTURE OF WIRE.

Having now described briefly the various kinds of metal used in the manufacture of wire, it will be necessary to explain the methods of wire making, or such as apply to the sort of wire that is used for fencing.

The ingots already described, after cooling in the molds, are reheated to a bright red heat, rolled down, and cut into lengths of a certain shape and size, known as " billets." Most wire-fence manufacturers buy either their wire or their billets from the steel mills, and comparatively few make their own steel. The horizontal heavy wires of a woven fence are usually made from a fairly high-carbon hard steel in order to attain great tensile strength or resistance to breaking under strain. The vertical or tie wires must of course bend easily without breaking, and they are made from a mild or soft steel, usually Bessemer metal. All metal used for fence wire at present made in this country is classed as steel, irrespective of the percentage of carbon or whether made by the Bessemer or open-hearth process. The billets are rolled hot into No. 5 gauge wire rod. This is then pickled in sulphuric acid until clean, then soaked in hot lime-water to remove the acid, and baked for about half a day, when it is drawn cold through dies of hard steel to the required gauge, usually No. 12. The lime coating on the wire lubricates it and prevents it from cutting out the dies. The wire is now ready for galvanizing, which consists of running it through brick tubes or ovens which are heated by coal or gas, where the process of annealing or softening takes place. When the wire is cool enough it enters a bath of acid, which cleans it and removes any scales that may have formed during the process of annealing. This so-called " pickle " consists of diluted muriatic acid and is a necessary treatment, as the wire would not take the zinc unless it had first been through the acid bath. The question as to whether the acid should be washed from the wire before it enters the zinc bath is important and manufacturers seem to differ in their practice. It is by no means certain that acid included in the zinc and under it will not tend to corrode the metal rapidly. Some sort of chloride is undoubtedly necessary

to make the iron take the zinc, but it is natural to suppose that the presence of actual acid should be avoided.

The wire is next run into a vessel about 16 feet long containing melted zinc. As the wire emerges from the zinc bath it is run through asbestos wipers, which wipe off nearly all of the zinc and leave a smooth coating, which amounts usually to about 1 to $1\frac{1}{2}$ per cent of the wire. The discussion of the method of galvanizing will be reserved for a separate section; it is sufficient to point out at this place that the coating of zinc furnished by this single process is very thin, and therefore presumably more perishable than a thicker coating would be. After the wire is galvanized, if a woven-wire fence is to be made, it goes to the weaving room, where the finished product is turned out. In some cases, especially in the manufacture of fine wire fencing, such as poultry mesh, the galvanizing is done after the weaving.

INVESTIGATION OF THE CAUSES OF FENCE-WIRE CORROSION.

Having now followed the processes of the manufacture of steel-wire fencing from the ore to the finished product, we are in a position to consider intelligently the information that has been obtained by means of a rather long and detailed investigation.

EXAMINATION OF SAMPLES OF WIRE.

Evidently the first thing to be done was to prove beyond all doubt that the older wire, as claimed, did outlast modern steel wire; and secondly, to determine, if possible, the reason for this. A large number of letters were received from all over the country in response to official inquiry, and all pointed in the same direction. As far as human testimony is capable of establishing a fact, there need be not the slightest question that modern steel does not serve the purpose as well as the older metal manufactured twenty or more years ago.

A great number of samples of wire were sent to the Division of Tests, and a series of analyses were made to see whether chemical analysis would throw any light upon the subject. In a paper of this kind it is not desirable to go too deeply into scientific and technical details, and therefore no tabulated results of analyses will be given. It is sufficient for our present purpose to state that it soon became noticeable that the majority of the old wires sent in which were in good condition were either free from manganese or contained only very small amounts—0.2 per cent or under of this metal. It is true that many of the good wires ran as high as 0.5 per cent and even higher in manganese, but the fact was nevertheless noticeable that the bad wires, with very few exceptions, contained manganese, while the good wires were frequently if not always free from it.

MANGANESE CONTENT OF STEEL AS AFFECTING OXIDATION.

The results of these preliminary experiments pointed undoubtedly to manganese as having something to do with the matter. The great difficulty was in explaining the exceptions. After a great deal of experimental work had been done in the chemical laboratory, however, one possible explanation appeared that might account for the facts obtained. Manganese dissolved in iron up to a certain percentage is known to increase the electric resistance of the metal. This means that iron wire containing manganese will resist the passage of electricity through it to a greater extent than a wire that contains little or no manganese. In case the manganese were not dissolved or mixed with perfect uniformity throughout the iron, electrical currents might be generated in the wire when wet, which would lead to rapid corrosion, as will be explained later. In order to get a practical opinion as to whether manganese was thought to have anything to do with the lasting quality of steel, the president and general manager of a company which is an enormous consumer of wire was appealed to, with the result that the following opinions which had been formed as the result of practical experience were received:

I. Bessemer or mild steel wire will rust or deteriorate much more rapidly than iron wire, in all probability three times as rapidly, although this is only an approximation.

II. The more manganese there is present the shorter will be the life of the metal.

III. In soft steel the manganese will reduce the conductivity of the wire fully 50 per cent below the conductivity of wire containing only a trace of manganese.

It seemed from this that, before the laboratory investigation instituted by the Department of Agriculture had been made, practical experience had indicated that manganese was at the bottom of the trouble. In order to show that there was still more authoritative evidence pointing in the same direction, it will be necessary to quote from a paper, by Mr. James P. Roe, on the "Manufacture and characteristics of wrought (puddled) iron," which was presented before the Washington meeting of the American Institute of Mining Engineers in May, 1905. The author says:

That wrought iron resists oxidation better than steel is becoming the general opinion of those who have studied the question under actual working conditions. The difference is naturally more apparent in thin objects, such as corrugated roof sheeting, tin plate for roofing, and the like; but its influence is the same regardless of mass. The difference in the life of light sections is about as 5 to 1 in favor of puddled iron.

The explanation of this resistance to oxidation is twofold:

(1) The cinder, a ferrous iron silicate enveloping each fiber, is much attenu-

ated by rolling, and in that condition is elastic. A piece of iron fresh from the rolls is covered with relatively thick scale, which will readily crack off to a large extent, exposing a surface of iron fibers with its intervening cinder. These fibers oxidize somewhat rapidly, leaving a finely corrugated surface of cinder, which resists further atmospheric action, as may be seen in heaps of scoriæ from old hearths believed to date from before the Christian era. Being elastic, it resists for considerable though varying periods; but eventually it cracks off under vibration, expansion and contraction, or mechanical wear. The cycle is then repeated, and so on.

(2) Puddled iron is a mechanical combination of two substances, iron and cinder, which offer differing resistances to such pressure as that of rolls or hammers. The result is a rough surface, which forms a more lasting bond with any protecting agent, such as tin or paint, than the smooth surface of steel, which does not aid in any way the adhesive qualities of the protecting agent.

In connection with the question of oxidation I may instance the experience of a large tube works carrying a considerable stock of iron tubes and accustomed to take from and add to the top of the stock pile without regard to the tubes in its lower part, knowing that these, when ultimately reached, would be found to be corroded uniformly over their whole surface, but could be rerolled to a lighter gauge, producing perfect tubes. After beginning to make steel tubes they followed the same practice; but these tubes were found, after rerolling, to be pitted through, and therefore valueless.

I am indebted to Doctor Raymond, secretary of the Institute, for the suggestion contained in the following communication:

In preparing your paper for the press I notice that you have omitted to mention, in connection with the question of the more rapid oxidation of soft steel, a chemical reason, namely, the presence of manganese in the metal. Many years ago, as consulting engineer of the firm of Cooper, Hewitt & Co., I approved the substitution of low-carbon steel for wrought iron for certain articles of manufacture. The immediate result was complaint from both consumers and selling agents that these articles rusted so soon as to look old, even upon delivery. A careful investigation, conducted for the firm by the late Dr. T. M. Drown, located the source of this trouble in the manganese of the low steel, or "ingot iron." In that particular case the rapid surface corrosion probably did not affect the real usefulness of the articles. But it may easily be inferred that when a coating of tin, zinc, or paint is applied to a sheet of metal a very slight extra liability to oxidation in that metal may set up a series of chemical and galvanic reactions of destructive character.

I have had recent occasion to realize with surprise and consternation the imperative necessity of frequent repairs to roofs, pipes, etc., of tinned or galvanized iron. My trusted mechanic declares that all his customers are similarly affected, and protests that he can no longer obtain anywhere materials of this class as durable as they used to be. He thinks that something is the matter with the processes of coating with tin or zinc; but I shrewdly suspect that the trouble lies in the manganese of the metal coated and in the series of reactions which its easy oxidation initiates.

It seems to me that the "pitting" of steel to which you refer is directly due to manganese.

As a final bit of evidence a quotation from a letter will be included which was received from Henry M. Howe, an experienced metallurgist, and the author of several well-known books on iron and steel:

Under certain conditions—for instance, in the case of boiler tubes—there appears to be little doubt that Bessemer steel of quality very similar to that which is rolled out for wire apparently does rust more easily than wrought iron suitable for such wire. Three reasons may be assigned:

(1) The wrought iron contains a small quantity of slag or cinder through it, which may mechanically protect the iron from corrosion, the sheets of cinder acting like so much paint to keep the atmospheric oxygen away.

(2) In order to make this steel very soft, so that it will draw easily, it is likely to contain a quantity of blowholes, which form centers from which rusting begins.

(3) The steel contains much more manganese than wrought iron does, and this manganese may not always be distributed with absolute uniformity. Wherever there is the least lack of uniformity there is a difference of potential, which may lead to rusting.

With this evidence we may rest the case and safely accept, at least for the time being, the following two points:

(1) That modern Bessemer and open-hearth steel rusts much more rapidly than iron wire.

(2) That manganese, especially if it is unevenly distributed in the steel, is at least in part the cause of the trouble.

ELECTROLYSIS AND ITS EFFECTS ON WIRE.

In order to pursue the inquiry further it will be necessary to show just how the manganese can have the bad effect that it does. Nearly everybody has probably heard at some time that steel pipes and conduits are liable to corrosion, owing to electrolysis or galvanic action. As a word this may be satisfactory, but unless the exact character of the action which it describes is understood it is a very unsatisfactory explanation. If this paper were to sum up the whole investigation by saying there is reason to believe that the cause of the rapid deterioration of steel fence wire has been traced to electrolysis induced by unequal distribution of manganese or other impurities, perhaps some readers might justly complain of being little wiser than before. It is necessary, therefore, to define as simply as possible " electrolysis," " difference of potential," and several other terms which will be used in this discussion before proceeding further.

If we wish to generate in a house small currents of electricity with which to ring an electric bell it is necessary to purchase or make a simple form of electrical cell or battery. Reduced to its simplest terms, this usually consists of a strip of zinc and a strip of some other metal immersed in a more or less dilute solution of some salt. Common table salt would do, but for special reasons some other soluble salt, like chloride of ammonia, is usually selected. If now by means of a wire or other metallic conductor the zinc strip is connected with the other metal, an electric current flows through the circuit. Whenever this is able to happen, we say that there is a difference of potential between the zinc and the other metal. In general, whenever a difference of potential is established between two points in a metallic conductor or circuit a current of electricity will flow. If in the case

of the battery referred to, the current is allowed to flow through an especially constructed electro-magnet, it can be caused to ring a bell. In the same way if the current were strong enough it could be used to saw wood or to run a street car. In other words, electric currents, however small, represent energy and can be made to do work.

There is a great and well-known law of nature which tells us that it is impossible to get something for nothing. If work is being done in one place, something is being, so to speak, undone in another place to balance it exactly. Every person who climbs upon a street car pays a fare which represents, at least in some degree, the cost of the coal or carbon which has to be burned (oxidized) at the power house in order to move him. Every time the bell rings in the house the zinc in the battery is corroded or oxidized or burned up to represent the work done. Whenever, through the agency of a liquid conductor like a salt solution, a current of electricity moves in a circuit, this is known as electrolysis. Whenever electrolysis goes on, some chemical reaction takes place, which, for all practical purposes, can be likened to the oxidation or burning of some metal. If a battery were to be made, as could easily be done, in which iron took the place of zinc, then iron would be oxidized instead of zinc. If two pieces of iron of different chemical analysis—that is to say, containing different amounts of impurities—are dipped into a dilute solution of salt and the ends connected, it will be found that a difference of potential exists, an electrical current will flow, and, if continued, at least one of the iron pieces will be destroyed by oxidation. With this simple explanation of electrolysis in mind we may return to the consideration of the oxidation of iron and steel.

The tendency of iron and steel to rust or oxidize is a characteristic of the metal itself, independent of the presence of any impurities it may contain. No iron has ever been or ever could be manufactured that would not rust in moist air, unless it were protected by some sort of covering. There is, however, a very great variability in the way different irons rust. One will cover itself over with a superficial layer of oxide, which will then act as a coating protecting the metal for many years, while another will pit so badly that the corrosion eats to the heart of the metal in a short time. Samples of wrought-iron cut nails that had been exposed to the weather for forty years were sent to the laboratory and found to be in as good condition as the day they were bought, while samples of steel wire 4 years old, which were originally galvanized, have been received which were pitted to the breaking point. Our problem, therefore, is not to find a kind of iron that will not rust, but to determine the causes which lead to the kind of rusting which makes wire short-lived, whether it is furnished with a protective coating or not; and further than this,

to see if there is not some way in which we may eventually be in a position to insist upon specifications for steel wire that will be reasonably resistant.

Wire that is hung in the field is in just the condition to suffer from electrolysis if the metal is not perfectly homogeneous in structure; that is to say, if the manganese and other impurities are not perfectly distributed throughout the metal. All rain water contains small amounts of salts dissolved from the dust in the air, and is therefore a conductor of electricity. Water collected during a thunder shower is particularly rich in substances that conduct electricity, as the sparking of the lightning through moist air forms small quantities of nitric acid, and acids conduct electrical currents even better than salt solutions. A moment's thought will show that under the conditions cited we have all the elements present to cause electrolysis to take place. Differences of potential will occur in the wire, local circuits will be established through the wires or through the wires and ground, and currents will flow. Just as in the case of the bell battery, these currents can only be generated at the expense of something, and in this case it is the iron if it is not the zinc of the galvanized covering. This explanation is capable of accounting for the deep pitting observed in the corrosion of many wires, this pitting being characteristic of electrolytic action. It also accounts for the much more rapid corrosion of wire near the seashore, as the rain water in such a locality contains more salt and thus this action is hastened.

If manganese is unevenly distributed in the metal, why, it may be asked, have chemists generally failed to notice the fact in the course of large numbers of duplicate analyses that have so frequently been made? The answer to this question lies in the fact that such extremely small differences in the chemical composition as might easily escape detection in ordinary chemical analysis are still sufficiently large to account for slight differences of electrical potential. It is almost impossible to select two steel needles from the same package which, if tested against one another with sufficiently delicate electrical measuring instruments, will not show a difference, even though the chemical composition appears to be practically the same. Metallurgists claim that even when a molten bath of metal is very evenly mixed in the beginning the cooled ingot made from this metal will show a certain amount of unevenness, owing to what is technically known as " segregation," which takes place while the ingot is cooling. A recent investigator has claimed that manganese segregates much less than some of the other impurities, notably sulphur and phosphorus. So little is definitely known about this subject as yet, however, that more experimental evidence is necessary.

Although it is probable that the effects of electrolysis in a fence wire are extremely small, it must be remembered that they are continually going on whenever the wire is wet. While it is true that puddled iron is in large measure protected from corrosion by the presence in its fibres of mill cinder, this has nothing to do with the fact that in almost all modern steel woven-wire fences some wires will be found to far outlast others, independent of the original weight of the galvanized covering which they carry. If in woven wire fence all the wires would last as well as the best ones do, there would have been no complaints, and this investigation would never have become necessary. It is just this point of unevenness of lasting quality in wires from successive heats in the same mill, which have practically the same chemical composition, that is hard to explain by any theory but that of galvanic or electrolytic action. The manufacturers have believed that the whole trouble was in the unevenness in the weight of zinc covering that was put on the wire, but experiment and observations show that this is not so. Some wires will go to pieces before others, although there is no discernible difference either in the weight or quality of the zinc covering. In one fence which has been under observation for four years one wire was in perfect condition, although it carried a light covering of zinc, while the wire next to it was badly rusted from end to end. Careful chemical analyses were made of these two wires, and, in order to check the results secured, samples were sent to one of the most eminent iron chemists in the country. This chemist reported as follows:

We have examined these samples, finding as follows:

Constituents.	Good wire.	Bad wire.
	Per cent.	*Per cent.*
Carbon	0.17	0.17
Manganese	.45	.53
Phosphorus	.092	.096
Silicon	.070	.060
Sulphur	.059	.083

You will note that, so far as these two samples go, there is very little difference in the wire, and practically no explanation chemically as to why one should be good and the other bad. They might almost be from consecutive heats from the same Bessemer converter; I do not think they are from the same heat. Notwithstanding this similarity of analysis of the samples which we have examined, it is more than probable that there may be quite unequal distribution of the manganese in the two samples.

It would seem that the easiest way to prove once and for all whether unequal distribution of the impurities is at the bottom of the trouble would be to make a great number of analyses of samples taken from different parts of just such wires as these. Unfortunately, however, the slight but unavoidable errors of chemical analysis are apt to be as large, if not larger, than the slight differences we

are trying to detect. It is also probable that the problem is complicated by the variation of more than one element. For instance, the combination of manganese and sulphur is known to show a larger difference of potential to iron than manganese alone. It would be natural to suppose that the easiest way to correct the trouble would be to cut down, in the process of manufacture, as much as possible the impurities that are present, but the difficulties in the way of doing this will now be understood.

Leaving the subject of laboratory investigations, we may now turn to the result of observation in the field. Almost everyone who has taken the pains carefully to inspect woven-wire fence as it is exposed to the weather on the farm has observed that some of the wires go to pieces much more rapidly than others. The bottom wires lying close to the ground, which are kept wet in summer by the growth of weeds and grass and in winter by melting snow, are naturally the ones which we should expect to rust most quickly. As a matter of fact, however, they almost never do so, but on the contrary are far more lasting than the wires farther removed from the ground. This observation has been substantiated by a large number of competent observers. Furthermore, wires that are stapled to living trees will almost invariably be preserved to some extent in the immediate neighborhood of the point of contact. One explanation that has been offered for these undoubted facts is that a certain protection from wind and weather is furnished by the growth about the wires, but this explanation is far from satisfactory. One would not seek to preserve iron from rust or zinc from corrosion by laying these metals away in wet snow or weeds. If, however, electrolysis takes place, and if the action can be diminished by keeping the wires electrically neutral through frequent connections to the earth, or through frequent short circuits, we should then expect that wires which were kept along their whole length in constant contact with the earth would, in the long run, show greater lasting quality. Experiments are at present being made to test the effect of earthing the fence by frequent connection to the ground. It is not easy to carry on a discussion of this highly technical subject in a paper of this nature, and it must be left for future presentation elsewhere.

THE PROCESS OF GALVANIZING WIRE.

The consideration of the protective effect of covering wire with a coating of zinc has been purposely put off up to this point. Why, it may be asked, does the quality of the steel make any difference, if it is to be covered with a protective coating of zinc? The answer is simple. It is extremely unlikely that any coating is sufficiently waterproof or sufficiently elastic not to develop numerous cracks and open-

ings through which water can act and electrolysis begin. Once begun, the electrolytic action corrodes zinc even more rapidly than it does steel. This may explain the very rapid disappearance of the galvanized covering from some wires and its great tenacity on others.

It will now be necessary to explain briefly the methods and practice of covering wire with zinc. In the first place, the word " galvanizing " as used gives a wrong impression. It is possible to dissolve zinc in an acid and then by means of a galvanic current, by the very principles of electrolysis properly controlled that we have been discussing, to deposit it as a coating upon another metal like iron. It has been shown that this method will give the most adhesive coating of zinc upon iron that it is possible to obtain. When we think, however, of the large amount of wire fencing made and the price for which it must be sold, one might as well consider plating it with gold as to suppose that fence wire is to receive a true galvanized coating. The universal custom is to pass the wire, when manufactured for fencing, after it has been cleaned with acid, through a molten bath of zinc, and then through asbestos wipers, as has been described in an earlier part of this paper. The object of the wipers is to remove all excess of zinc and make the coating smooth.

The zinc ordinarily used for fence wire is known as " spelter." It is made of virgin ores and consists of about 99 per cent of zinc, 0.1 per cent of iron, 0.5 per cent of lead, and occasionally cadmium and some other elements, depending on the location of the zinc mine. The ordinary weight of the zinc protective coating per unit weight of wire for fencing purposes is made as small as possible, and will often run as low as from 1 to 1.5 per cent. The temperature of the galvanizing bath should be kept as low as possible to prevent excessive drossing of zinc and disintegration of the metal.

A very much better covering and perhaps a more durable wire can be made by what is known as the double galvanizing process. The double process does not, as its name implies, mean that more than one coating of zinc is put on, but only that about twice as much zinc by weight is carried by the wire. In the double process the wire is drawn much more slowly through the zinc bath and does not pass through asbestos wipers, but is smoothed by passing through a shallow bed of slightly damp charcoal powder. Telegraph wire is usually treated by this method and is generally acknowledged to be more durable than fence wire, but it is worth noting at the same time that care is exercised in the manufacture of telegraph wire to keep the manganese low, because the presence of this element increases the electrical resistance of the wire. The difficulty experienced in rolling low-manganese steel and the slow rate of speed at which the mill must be run to draw the wire through the zinc bath in the double

process adds materially to the cost of the product. It is a question that can not be decided here, whether or not high-grade fence wire is worthy of the same care and consideration that is given to wire which brings a higher price in the market and which is intended for other purposes.

Although, as has been said in an earlier paragraph, it is not the intention to maintain that the weight of the galvanized coating has nothing to do with the lasting quality of fence wire, in view of the evidence which has been collected it is impossible to believe, as many people do believe, that insufficient galvanizing is the whole cause of the difficulty. Among the wire fences that have been under the careful observation of the writer for a long time is one woven-wire fence 5 years old that contains among its twelve horizontal wires, all of one roll, seven wires that are perfectly good from beginning to end, four that are partially rusted, and one that is badly rusted, without a particle of zinc remaining on it. Of the seven perfectly good wires, six are on the bottom. Now, if the theory of electrolysis is left out of the question it would seem that the good wires had received a better coating of zinc than the bad wires. This explanation is not supported either by observation or experiment. Two wires are made in the same mill; pass through the same zinc bath; are wiped off in precisely the same way; chemical analysis shows them to have practically the same weight of zinc covering per pound of metal; and yet one wire will outlast the other 5 to 1 on the fence. It is, however, entirely possible that the perfection with which the manganese and other impurities are distributed may happen to be more perfect in one ingot than it is in another. Within certain practical and possible limits it is probably true that, other things being equal, the wire with the heavier zinc coating per unit of surface area will be the most resistant to weather conditions.

None the less, in the opinion of the writer and for the reasons outlined in the foregoing pages, the problem will not be solved until attention is directed to obtaining the proper conditions in the wire itself. Although the Department of Agriculture can not undertake to make specifications, it is highly probable, now that the attention and interest of manufacturers has been aroused, a substantial improvement in the rust-resisting character of fence wire will follow in the future. One of the prominent manufacturing companies claims to have already solved the problem of making a better wire. If these expectations are justified, and even if such improvements remain to some extent trade secrets, there is no question but that the farmer will soon begin to get the benefit of the better quality of fencing, which will result from the persistent effort on the part of manufacturers to improve their product and distance their competitors.

APPENDIX.

THE MANUFACTURE OF WROUGHT IRON AND THE RELATIVE RESISTANCE TO CORROSION OF WROUGHT IRON AND STEEL.

At a meeting of the American Institute of Mining Engineers, held in Washington, D. C., in May, 1905, Mr. J. P. Roe read a paper on the above subject, and the following discussion took place:

DR. CHARLES B. DUDLEY, *Altoona, Pa.*: Those of us who are using metals continuously can not help noticing at the present time a distinct trend toward a return to the use of wrought iron in place of steel in certain constructions. It is well known that for the last twenty or twenty-five years the trend has been markedly in the other direction. Wherever possible, steel has been substituted for iron, and it may be said with all honesty that the belief and feeling of those who have guided this matter have been that the substitution of a homogeneous, well-made metal like steel for a non-homogeneous metal like wrought iron, which is apt to be full of flaws and bad welds, was not only wise, but clearly a step in the right direction. However, as we have obtained more experience with the use of steel (and I may say that it has apparently taken about twenty years to get this experience) we are finding that in certain constructions steel is not proving to be as satisfactory as we had hoped. This may be due partly to lack of knowledge, which has led us to use steel of a grade not fitted to the work, and it may be partly due to the design, since, when we change from one metal to another, it does not necessarily follow that the same construction and size of parts will give satisfactory results; and it may be partly due to workmanship, since it does not necessarily follow that the two metals can be treated exactly alike. Whatever the cause, the difference in the behavior of the two metals in service, at least in certain constructions, is very clear. We are inclined to think there is a fourth cause, perhaps more important than any of those already mentioned, namely, the nature of the two metals. * * * Iron and steel do not behave alike when subjected to bending stresses. We think it is perfectly safe to say that a well-made iron car axle, the metal of which will show in tensile strength from 48,000 to 52,000 pounds per square inch will stand successfully the same fiber stress as steel of 80,000 to 85,000 pounds tensile strength. Just why this is so I am unable to explain, but there is a very large amount of accumulated experience which seems to indicate that a metal like iron, which is believed to be a bundle of fibers, each one surrounded by slag, and which has within itself the power of the distribution of the strain, is a more reliable metal when subjected to bending stresses than a perfectly homogeneous metal like steel. This is hardly the place or the time to go into a discussion of this phase of the case, and so I close by saying that the present outlook seems to be that, if wrought iron can be made in sufficiently large masses, so that flaws and defective welds will be eliminated, it might again become a successful rival of steel, especially if it can be made at a cost that will permit of commercial competition.

DR. ALLERTON S. CUSHMAN, *Washington, D. C.*: My connection with this discussion is rather indirect, because I make no claim to have had very much

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experience in the problems that are presented to iron and steel men, whether manufacturers or users, but I occupy the position of chemist in the Division of Tests of the Department of Agriculture, and so many complaints have reached the Department as to the lasting quality of modern steel wire which is sold to American farmers for fencing purposes that the Secretary and the Assistant Secretary of Agriculture have interested themselves in the problem, and have asked me to investigate it, or at least to begin the collection of data with a view to making a thorough investigation of the whole subject.

I knew of no reason why modern steel wire should not last as long as the older wires. Inquiries among men who have had a large experience did not lead to any satisfactory source of information. Text-books on the metallurgy of iron and steel contain contradictory statements, and the question seems to be one as yet unanswered.

Several of the influential farmers' journals in the country have taken up the matter, and in every issue we are reminded that something ought to be done. Farmers complain that galvanized steel wire fences go to pieces in two or three years, and yet some of these farmers have fences on their farms which were put up thirty years ago. I am not ready to report upon what we have done so far in any direct way, because the work is very young.

After having examined carefully in the laboratory samples of iron and steel wire that had failed and of wire that had not failed, we noticed that those which had failed contained manganese as high as 0.4 per cent in the large majority of cases, while wires that lasted did not contain manganese at all. If, however, the solution were as simple as that it would not have been a problem, and we realized that this point would have been observed long ago. As a matter of fact, it is not so simple.

We thought that perhaps the best way to begin was to get as pure iron as possible by the Goldschmidt-Thermit process and commence with that, and then see if we could work out a laboratory method of studying the problem. The first thing we did was to make laboratory ingots with different percentages of manganese. By making ingots of definite composition we thought we might perhaps work out a laboratory method of determining the relative rate of oxidation.

As far as we have gone this much seems to be true: Iron which is free from manganese is not so readily oxidized by very dilute solutions of hydrogen peroxide as those irons which contain appreciable amounts of manganese. The very dilute solutions of hydrogen peroxide that we used are not unlike rain water—that is to say, thunder-shower water. It is easy to make in the laboratory solutions of nitric acid, carbonic acid, etc., and thus approximate the conditions that wire is subject to out of doors, i. e., rain water containing small amounts of hydrogen peroxide, carbonic acid, nitric acid, sulphuric acid, and other constituents.

A number of samples have been collected from farmers. Some were found in very good condition and others in extremely bad condition after thirty years of service. We believed that the good wires would prove to have no manganese in them and that the bad wires would run high. As a matter of fact, it did not invariably turn out that way; but I think it is safe to say that in the majority of cases, and especially with the modern steel wires made by the Bessemer process, the presence of manganese does increase the rate of oxidation—that is, manganese has something to do with it directly. With the iron wires, so far as we have gone, it does not look as though the manganese had so much to do with the matter. It naturally occurs to one that the distribution of manganese in

the metal may possibly be the cause of the trouble. If we have manganese very evenly distributed throughout the mass of the metal, electrolytic action need not necessarily be set up, but if there be an unevenness in the distribution of the manganese, then electrolytic action leading to pitting and pockmarking of the iron may take place. All we can do is to speculate pending a systematic investigation of the matter, which it seems to me has not yet been made by anyone.

The Department of Agriculture has determined to find out, if possible, why these fence wires go to pieces so rapidly, and hopes that manufacturers will cooperate in discovering the reasons for the trouble.

The wires were badly pitted or pockmarked. If the whole surface of the iron had rusted it would not have been so bad, but in nearly every case the old iron fence wire was badly pitted, and sometimes these pits extended nearly through and then the wire would break. You remember that in the old days they made wire heavier than now. The increased tensile strength of steel enabled them to use less metal for the same strength, and that has something to do with it. Then, further, exposure to the action of the elements plays an important part. To-day they twist the strands of wire, thereby forming little cups where the water is lodged, allowing a rusting point. Making every allowance, there is no doubt that modern wire is not as lasting as it should be.

I am told by men who are using steel pipe that, as compared with iron pipe, steel pipe pits, and there are many in this country who are discontinuing the use of steel pipes for this reason. My experience leads me to the same conclusion that Doctor Dudley has reached ; that is to say, that the time is coming when perhaps a return to the older processes is going to yield a metal better suited to certain purposes than the more convenient modern processes.

J. E. JOHNSON, Jr. : Did you ever make any comparison of the contents in sulphur and manganese? This may be important, because the manganese will be present as sulphide of manganese as long as there is any sulphur to take up, and probably some will be in the form of sulphate.

DOCTOR CUSHMAN : I realize that the problem is complex and that the inquiry suggested would be very interesting, and, like other collateral investigations not yet executed, must be made before a final solution can be reached. I do not think anyone knows whether the action of the manganese is catalytic in its nature or whether it is due to the mere fact that manganese oxidizes rapidly, or, again, whether the action is electrolytic.

JOSEPH HARTSHORNE, *Pottstown, Pa.:* It is, of course, well known that the chemical composition of iron and steel has a great influence upon their resistance to corrosion. For instance, the presence of any nickel retards oxidation, and a sufficient quantity will prevent it entirely. It seems very probable, therefore, that, as suggested by Doctor Raymond, manganese has a decided effect and that it is in favor of oxidation, but I do not remember any report of tests bearing directly on this point.

Other elements undoubtedly exercise considerable influence. In this connection, a series of tests made by Engineer Diesel, of the German torpedo service, are important. They cover the relative corrosion of certain alloys by sea water.[a] Among these alloys was " flusseisen," or soft steel. The results on this material show that phosphorus has a protective effect against corrosion, since the plates with high phosphorus resisted corrosion better than those low in phosphorus. They also show that there is an electrolytic action between plates of different

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[a] Stahl und Eisen, May 30 and June 15, 1904.

contents of phosphorus when in contact, whereby the low phosphorus plate corrodes much faster than when isolated or in contact with plates containing like amounts of phosphorus.

The extreme probability that the presence of manganese increases the liability to corrosion, while that of phosphorus decreases it, affords a good reason why puddled iron should resist corrosion better than steel, since iron rarely contains more than a trace of the former element and usually contains very much more of the latter than is allowable in steel.

Like all laboratory experiments in this line, however, those just referred to, while very interesting and important, are merely indicative and not demonstrative. The samples used in such tests are not subjected to the ordinary conditions of practice and the results obtained may or may not correspond to those obtained in practice. For instance, the samples are merely suspended in the attacking medium—such as sea water, dilute solutions of mixed acids, hydrogen peroxide, etc.—in a quiescent state, while in practice the surface is generally subjected to movement and stresses of various kinds. From this it results that the rust is shaken off as it forms and fresh surfaces are continually exposed. I do not mean to assert that this action always hastens corrosion—under some circumstances it might even retard it—but merely to point out the inherent differences between the two sets of conditions.

Such experiments can only show the relative rates of corrosion of the substances investigated under the conditions given. They may indicate, perhaps very definitely, the probable rate at which the substance will corrode in practice, but can not determine it with, say, anything like the accuracy that an analysis for phosphorus will show the capacity to resist shock. The only way in which this question can ever be settled, it seems to me, is by the collation of as many examples from actual practice as possible, preferably those in which iron and steel are used side by side under the same conditions, either intentionally for comparison or incidentally.

As examples of what I mean I will refer to two incidents in my own experience, although many of you have probably met with the same. A Bessemer steel works was built under my supervision in 1885, the roof and sides of which were made of corrugated iron sheets of heavy gauge. They received two coats of paint on both sides before erection and one on the outside when in place. The sheets were put on in the latter part of 1885; blowing began in July, 1886, and ceased finally in August, 1893. Since that time most of the buildings have been entirely neglected. Extensions were erected at various times, generally after 1889, for which steel sheets of the same gauge were used and treated in the same way. The parts of the first roof (of iron sheets) immediately over the cupolas and converters were renewed twice during the eight years of running, but the rest of it was not touched, except to repaint it once on the outside. Much of the roof and a still larger proportion of the sides will still turn water after twenty years, although they have not been painted for eleven years and the wind has had free play with the sheets, which were never fastened if they got loose. None of the steel plates lasted over four years, and a part which was reroofed with steel sheets in May, 1901, now requires renewal.

In 1885 a smoke flue, made of galvanized sheet iron, was put in with the furnace of the house I then occupied, and when I left it in 1893 it was apparently in as good condition as when new. A flue similar to the other in every respect, except that it was made of sheet steel, was put into my new house in 1893, in connection with a furnace of the same size and make and under the same general conditions of firing, but in a drier cellar. This flue has been renewed twice in the twelve years since then, on account of having rusted out.

In my experience with tinsmiths and roofers, I find that there is a general complaint that the galvanized and tin sheets of the present do not last anything like as long as those made twenty-five or thirty years ago. The old men who have had experience with both kinds say that the present sheets last only a fourth or a fifth as long as the old ones. Only a few attribute this to the old sheets being made of iron and the present ones of steel; but, on the other hand, few of them know this fact or appreciate what it means.

I was very glad to hear Doctor Dudley, whose opportunities for investigation and observation are unsurpassed, indorse the remark I made this morning in announcing this discussion. My own investigations had led me to believe that iron was the better material for many of the purposes to which steel is now applied, and it seemed to me that the decided trend of opinion, not only among tradesmen, but also among engineers and investigators, was in the same direction. If this opinion be warranted by the facts, as now, more than ever, I think it is, then the use of iron must largely increase in the near future.

MR. N. B. WITTMAN, *Philadelphia, Pa.:* Several years ago, during the latter eighties and up to the early nineties, the substitution of both Bessemer and open-hearth soft steel for purposes previously held by wrought iron caused many capable observers to hold the view that wrought iron would soon fill but an unimportant part in metallurgy. In looking over the Directory of the American Iron and Steel Association, the rapid decline in the number of active puddling furnaces reported up to the year 1898 will be noted. The entire withdrawal of such important firms as the Carnegie, Cambria Steel, Jones & Laughlins, and others from puddling was responsible for the greater part of the decline. Since 1898 this movement, on the whole, has been checked and a study of the " directory " will show a very important increase in the number of active puddling furnaces in certain localities and among old-established firms who have held to iron for certain purposes irrespective of locality. In eastern Pennsylvania to-day many new puddling furnaces are being built, and even in Pittsburg many of the firms which have held to the iron business are larger puddlers than in 1898.

The superior shopworking qualities of soft steel, together with attractive physical tests and analyses, naturally commend it, but the test of use unquestionably shows that for many purposes it is not so durable as iron. Several years ago the iron nail was practically driven out of the market by the cut-steel nail; after a time it was found that structures nailed with steel nails would not hold because the nails rusted off under the heads very rapidly; it was also found that for scaffolding and similar purposes cut-steel nails had less holding power than cut-iron nails, and a demand has again sprung up for the cut-iron nail; the tonnage of the latter at present produced is still small, but it is large compared with what it was several years ago and is still growing.

For wrought-iron pipe, notwithstanding the higher cost of production, the demand has been sufficient to employ several important works exclusively for the manufacture of this product. For boiler tubes steel has not been satisfactory, and, although almost all new stationary boilers are equipped with steel tubes, principally because they cost about $1 per horsepower less and are preferred for easy working, the general experience has been that in most cases they are not so durable as the charcoal-iron tube and the greater part of locomotive tubes are made from charcoal-iron skelp. In this connection I know of an important steel manufacturer, and therefore without prejudice in favor of iron, who will not have a steel tube in the boilers nor a steel sheet on the roofs of the buildings.

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Another important concern, well known as producers of steel for special purposes, has not been able to make steel suitable for stay bolts, and it is increasing its iron-puddling capacity at this time, principally for the purpose of making stay-bolt iron.

In view of Mr. Roe's admirable statement concerning the structure of iron, I believe that if we could divest ourselves of prejudice and forget that we have ever regarded ourselves as iron men or as steel men and would use our metallurgical knowledge only in forming opinions, we would, in view of the stable nature of the silicate of peroxide of iron which envelops the grains of iron, and in view of the rougher surface which results from it, conclude that for holding protecting material and for resisting corrosive influences iron is superior to steel; while for deep-stamping purposes, requiring equal strength in all directions, and for purposes in which high tensile strength and elasticity are required, or for any purposes in which temper is essential, steel is obviously superior to iron.

JAMES P. ROE, *Pottstown, Pa.:* While steel has permanently displaced iron for many purposes, yet in some instances it has not proved satisfactory. Such instances are becoming more frequent, and many makers of finished material would welcome a change back to iron.

The investigation of the corrosion of iron and steel fencing wire that is being made by the Department of Agriculture will have far-reaching economic results. In iron the manganese exists as oxides in the slag, and therefore is not subject to further oxidation; in properly worked iron this slag is distributed with reasonable uniformity; that is, only such slag is present as envelops the original grains, being reduced somewhat in volume by subsequent work; in such a condition it offers its greatest resistance to corrosion. When an undue quantity of slag is present in pockets or laminations, it is fragile, cracks off readily, and possesses little protective value. Moreover, some samples for analysis might be taken by chance at points where pockets of slag exist, in which case the determinations would show a relatively high manganese content. On the other hand, the manganese in steel exists as metal held loosely as an alloy, a condition favorable to electrolytic action, especially if the manganese is unevenly distributed.

Mr. Hartshorne's remarks in regard to presence of phosphorus in iron increasing its resistance to corrosion are confirmed by my own experience in the relative corrosion of iron containing high and low phosphorus.

Mr. Wittman's reference to the increase in the number of active puddling furnaces in the United States is important, since it represents an increased demand for iron at a price materially higher than that of steel. The same condition exists in Germany, France, and England, and I am advised that the supply of puddled iron abroad does not meet the demand.

APPROXIMATE METHOD FOR ESTIMATING THE WEIGHT OF ZINC COVERING CARRIED BY A GALVANIZED WIRE.

It is possible that many users of large quantities of galvanized wire may be interested in the test by which the weight of zinc carried by any wire is estimated. The test depends upon the fact that if zinc is dipped into a strong solution of copper salt it goes into solution and copper comes out. As soon as the zinc is removed from the iron the copper begins to plate out on the wire and can be easily seen.

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In carrying out this test the following directions should be adhered to minutely:

A fair sample of the wire to be tested, about 6 inches in length, is thoroughly cleaned from grease and dirt by washing and careful wiping. A nearly saturated solution of copper sulphate (24° Baumé at 60° F.), which can be obtained from any chemist or druggist, is poured into a clean dry glass to a depth of about 3 inches. The clean wire sample is immersed with a quick motion in the copper solution, and at the end of exactly five seconds quickly withdrawn and at once dipped into pure water and wiped with a bit of clean filter paper or soft cotton cloth. The immersion should be timed with a stop watch if possible. As long as no copper is visible plated out on the iron, the five-second immersions are repeated until the copper deposit which begins to form wipes off with difficulty. At this point a series of rapid (two-second) immersions are made, with alternate wipings, until bright streaks of metallic copper, which can not be wiped off the wire, appear. The total time of immersion in minutes and fractions of a minute is taken as an indication of the percentage of zinc carried by the wire. Thus, if 150 seconds' immersion were necessary to reach the end point, the weight of the galvanizing would be called 2.5 per cent. It must be remembered that although the results of this test are approximate only, their value depends entirely upon careful accuracy in following out the directions. No attention should be paid to the copper which plates at the extreme tip end of the sample where the zinc has been cut away. If a user of fencing wishes to purchase wire advertised as extra heavy galvanized, he can tell by this method, with a fair degree of accuracy, with what he is being supplied. Some telegraph companies specify that telegraph wire must stand four-minute immersions, equal to about 4 per cent of zinc.

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FARMERS' BULLETINS.

The following is a list of the Farmers' Bulletins available for distribution, showing the number and title of each. Copies will be sent to any address on application to any Senator, Representative, or Delegate in Congress, or to the Secretary of Agriculture, Washington, D. C.

No. 22. The Feeding of Farm Animals. No. 24. Hog Cholera and Swine Plague. No. 25. Peanuts Culture and Uses. No. 27. Flax for Seed and Fiber. No. 28. Weeds: And How to Kill Them. No. 29. Souring and Other Changes in Milk. No. 30. Grape Diseases on the Pacific Coast. No. 32. Silos and Silage. No. 33. Peach Growing for Market. No. 34. Meats: Composition and Cooking. No. 35. Potato Culture. No. 36. Cotton Seed and Its Products. No. 37. Kafir Corn: Culture and Uses. No. 38. Spraying for Fruit Diseases. No. 39. Onion Culture. No. 41. Fowls: Care and Feeding. No. 43. Sewage Disposal on the Farm. No. 44. Commercial Fertilizers. No. 46. Irrigation in Humid Climates. No. 47. Insects Affecting the Cotton Plant. No. 48. The Manuring of Cotton. No. 49. Sheep Feeding. No. 50. Sorghum as a Forage Crop. No. 51. Standard Varieties of Chickens. No. 52. The Sugar Beet. No. 54. Some Common Birds. No. 55. The Dairy Herd. No. 56. Experiment Station Work—I. No. 57. Butter Making on the Farm. No. 58. 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Red Clover Seed: Information for Purchasers. No. 124. Experiment Station Work—XVII. No. 125. Protection of Food Products from Injurious Temperatures. No. 126. Practical Suggestions for Farm Buildings. No. 127. Important Insecticides. No. 128. Eggs and Their Uses as Food. No. 129. Sweet Potatoes. No. 131. Household Tests for Detection of Oleomargarine and Renovated Butter. No. 132. Insect Enemies of Growing Wheat. No. 133. Experiment Station Work—XVIII. No. 134. Tree Planting in Rural School Grounds. No. 135. Sorghum Sirup Manufacture. No. 136. Earth Roads. No. 137. The Angora Goat. No. 138. Irrigation in Field and Garden. No. 139. Emmer: A Grain for the Semiarid Regions. No. 140. Pineapple Growing. No. 141. Poultry Raising on the Farm. No. 142. Principles of Nutrition and Nutritive Value of Food. No. 143. Conformation of Beef and Dairy Cattle. No. 144. Experiment Station Work—XIX. No. 145. Carbon Bisulphid as an Insecticide. No. 146. Insecticides and Fungicides. No. 147. 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